

An Experimental Investigation of the Three Dimensional Flow in the Clearance Region of Cantilevered Stator Vanes With and Without Hub Rotation

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Abstract

The desire for better performance in industrial gas turbines is driven by global competition. Improvements in all aspects of industrial gas turbines, including the reduction of aerodynamic losses, is critical in this competition. To assess the improvements in aerodynamic performance of advanced blade designs, computational fluid dynamics (CFD) is utilized in the design and analysis process to reduce testing requirements and time to production. However, in order for CFD predictions to be of quantitative value, the flow modeling and numerical methods must be validated with high quality measurements. These measurements must accurately identify flow separation, secondary flows, clearance flows, and hub and tip vortices, since it is often these types of flow phenomena that are not well predicted by CFD.

Hence, the overall objective of this investigation is to provide benchmark three-dimensional experimental data in the end-wall regions of the stator vanes in a single stage compressor. In particular, the flow field will be measured in the clearance regions beneath (in the hub region) the cantilevered stator vanes for configurations where the hub is rotating and non-rotating. Clearance values of 1 percent and 3 percent of passage height will be investigated. The effect of these vane clearances and the rotating hub on end-wall separation and stalling pressure rise will be quantified. In addition, to enhance the usefulness of this experimental data for verification of the accuracy of computational models, complete flow-field mapping will be conducted at the rotor inlet plane, upstream of the stator vanes, and downstream of the stator vanes.

These measurements will be conducted in the UC Davis Single Stage Low Speed Research Compressor (LSRC). The overall experimental facility and airfoils are physically large. This amplified the fundamental flow physics and eliminates the necessity of extreme miniaturization of the instrumentation. The current cantilevered NACA 65 series stator vanes will be replaced with a modern cantilevered design that will be designed in collaboration with Solar Turbines, Inc. Two sets of vanes will be designed; Stator A will be designed for a rotating hub beneath the vanes, and Stator B will be designed for a non-rotating hub configuration. The design

of each set of stator vanes will be optimized to reduce hub clearance losses. The LSRC has been specifically designed to allow for both rotating and non-rotating hubs beneath the stator vanes. The rotor inlet and exit flow field will be measured to quantify the flow field for designing the new sets of vanes.

The data of fundamental interest in this investigation are the vane steady aerodynamic loading, the stator inlet and exit flow fields, and the clearance flow field. Stator vane aerodynamic loading will be quantified using span-wise and chord-wise distributions of airfoil surface static pressure taps. The span-wise biased static pressure taps will be used to quantify the loading and separation regions near the stator clearance gap. Vanes with pressure and suction surface taps will be used. The unique feature of this research program will be the measurement of the flow field in the clearance gap beneath the stator vanes. This will be accomplished using Particle Image Velocimetry (PIV). This technique enables complete two dimensional flow fields to be obtained without directional ambiguity.

This program will provide an extensive set of benchmark experimental data that can be used to evaluate the capability of current state-of-the-art computational models to accurately predict flows in the end-wall and clearance regions. Once validated, the tip clearance models can be used to develop passive methods of airfoil and/or end-wall contouring to reduce clearance losses and therefore increase compressor performance.

The team members for this research program are UC Davis and Solar Turbines, Inc. This three year research program has just started.

Acknowledgment

Support of this Advanced Gas Turbine Research program by the U.S. Department of Energy, Federal Energy Technology Center, Cooperative Agreement No. DE-FC21-92MC29061, Subcontract No. 96-01-SR048. Dr. Norman Holcombe as DOE Project Manager, and Dr. Daniel Fant as the AGTSR R&D Manager, are gratefully acknowledged.

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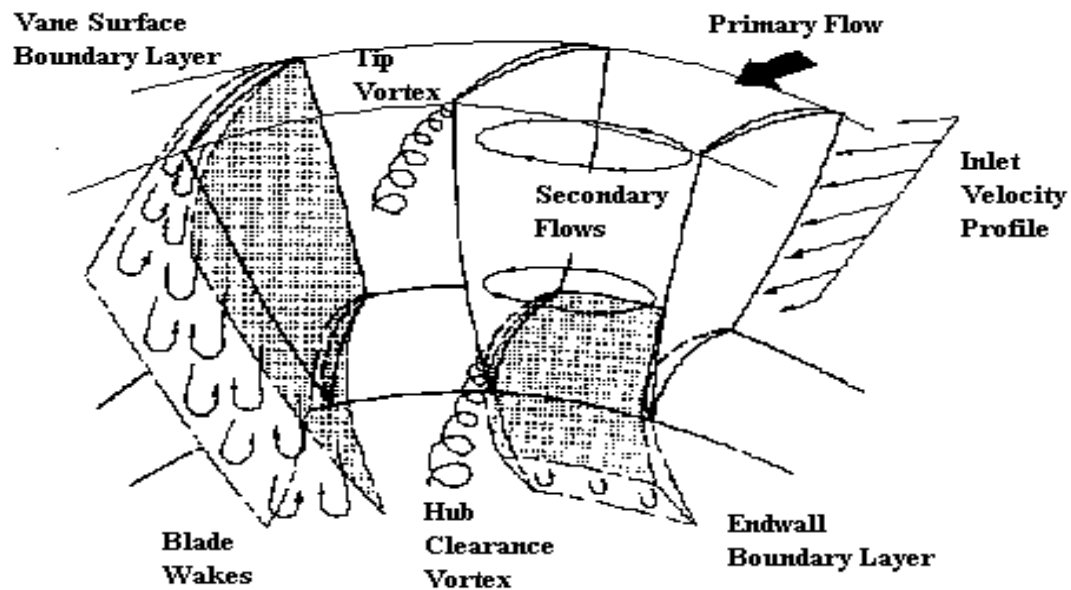
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BACKGROUND

The flow structure in axial flow compressor blades is extremely complex



BACKGROUND

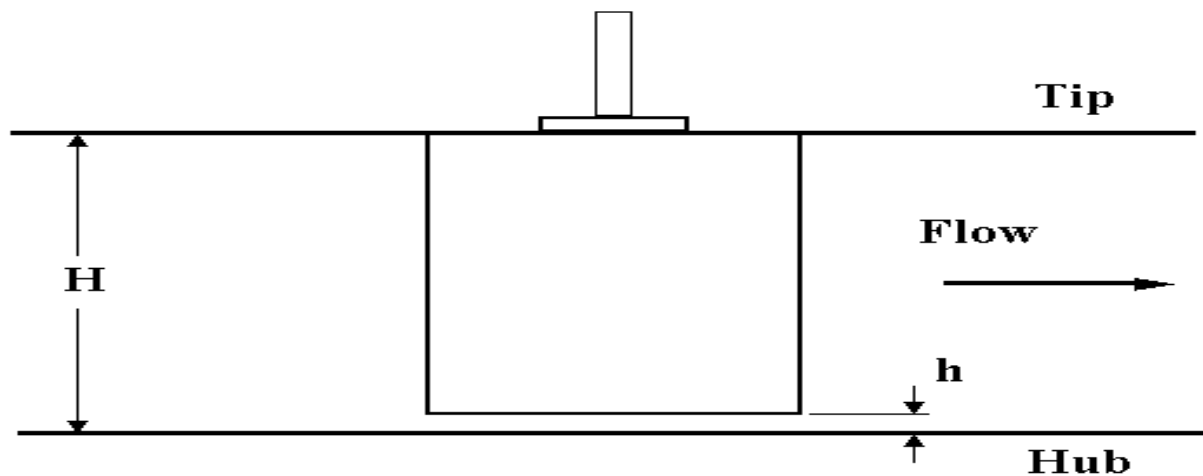
The most complex flow features occur in the endwall regions where the clearance gaps exist

- **Flow phenomena not well understood in this area**
- **No satisfactory aerodynamic loss prediction technique in this area**
- **Empirical correlations from previous testing experience most commonly used**

RESEARCH OBJECTIVES

Experimentally investigate the 3D flow in the hub clearance region of tip cantilevered stator vanes in a single stage compressor

Gap Height = h/H



RESEARCH OBJECTIVES

- **Provide benchmark data for validation of clearance models in Computational Fluid Dynamic (CFD) analyses**
- **Quantify the following effects on stator vane performance**
 - **Clearance gap height**
 - **Hub rotation**

TECHNICAL APPROACH

Map flow field in low speed, large scale research compressor

- **Measure flow in stator vane hub clearance gap using Particle Image Velocimetry (PIV) for 1% and 3% gap heights**
- **Measure stator vane surface pressures**
- **Measure flow field at rotor inlet, stator inlet, and stator exit**
- **Correlate measurements with appropriate CFD predictions**

TECHNICAL APPROACH

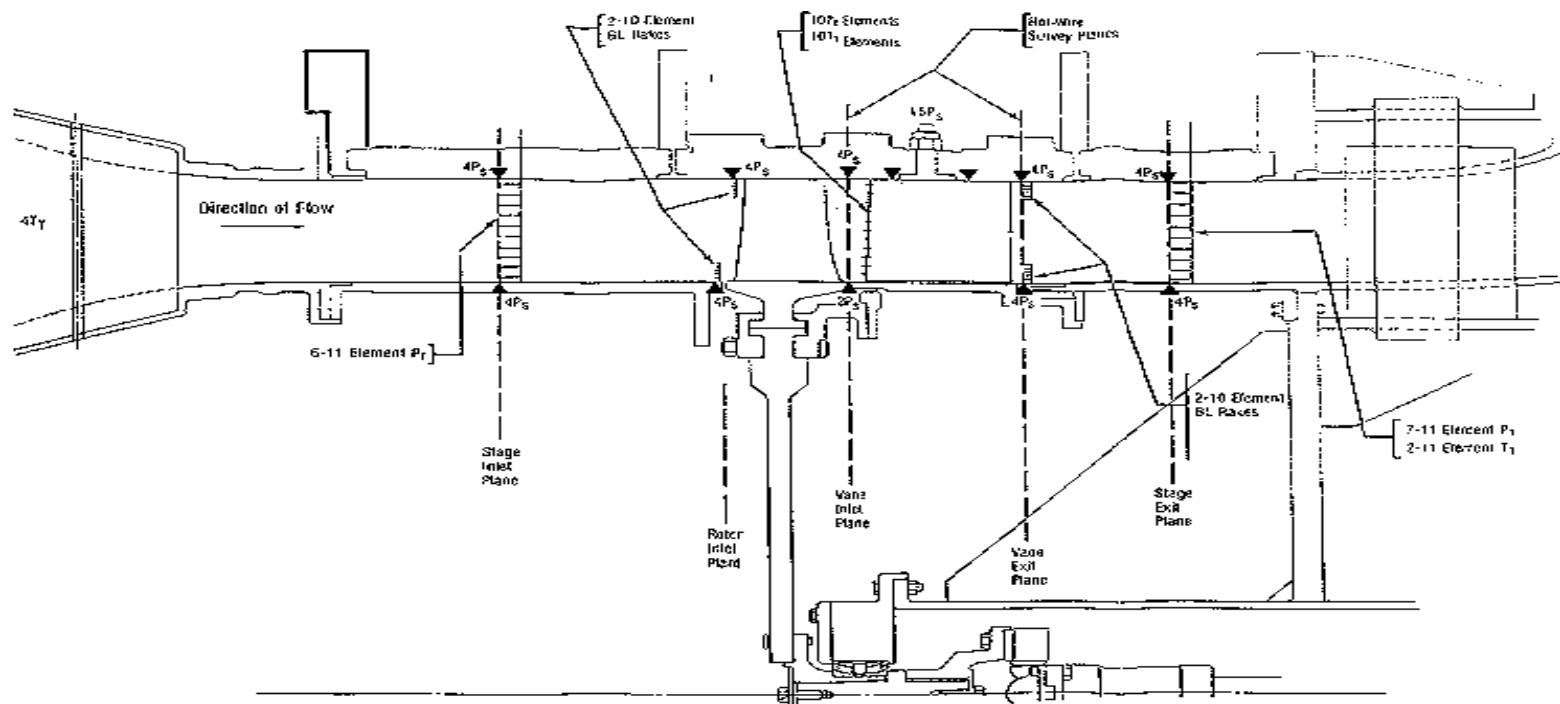
Objectives will be accomplished in two separate experiments

- **Replace current NACA 65 Series stator vanes with a modern cantilevered design**
 - **Vanes will be designed in collaboration with Solar Turbines, Inc.**
- **Two sets of vanes will be designed and their aerodynamic performance experimentally quantified**
 - **Stator A for hub rotation**
 - **Stator B for no hub rotation**

EXPERIMENTAL FACILITY

UCDavis low speed research compressor can model flow in stator vane clearance region

- Fully instrumented single stage machine
- Rotating & nonrotating hub configurations supported



EXPERIMENTAL FACILITY

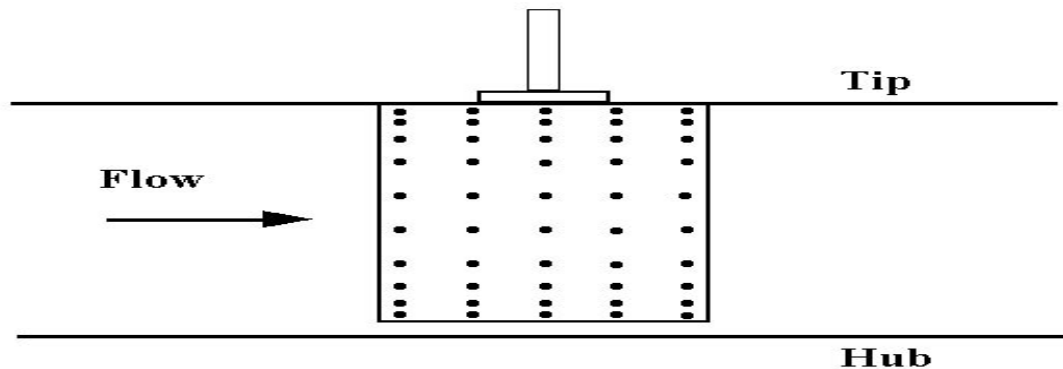
UCDavis low speed research compressor blading design models the mid stages of a core compressor

- **Airfoil counts**
 - **42 Rotor blades**
 - **40 Stator vanes**
- **Mid span airfoil geometry**
 - **Hub/Tip Radius Ratio = 0.80**
 - **Stage Efficiency = 88.1%**
 - **Rotor design**
 - **Solidity = 1.435**
 - **Dfactor = 0.45**
 - **Aspect ratio = 1.046**
 - **Stator design**
 - **Solidity = 1.516**
 - **Dfactor = 0.41**
 - **Aspect ratio = 0.943**

INSTRUMENTATION

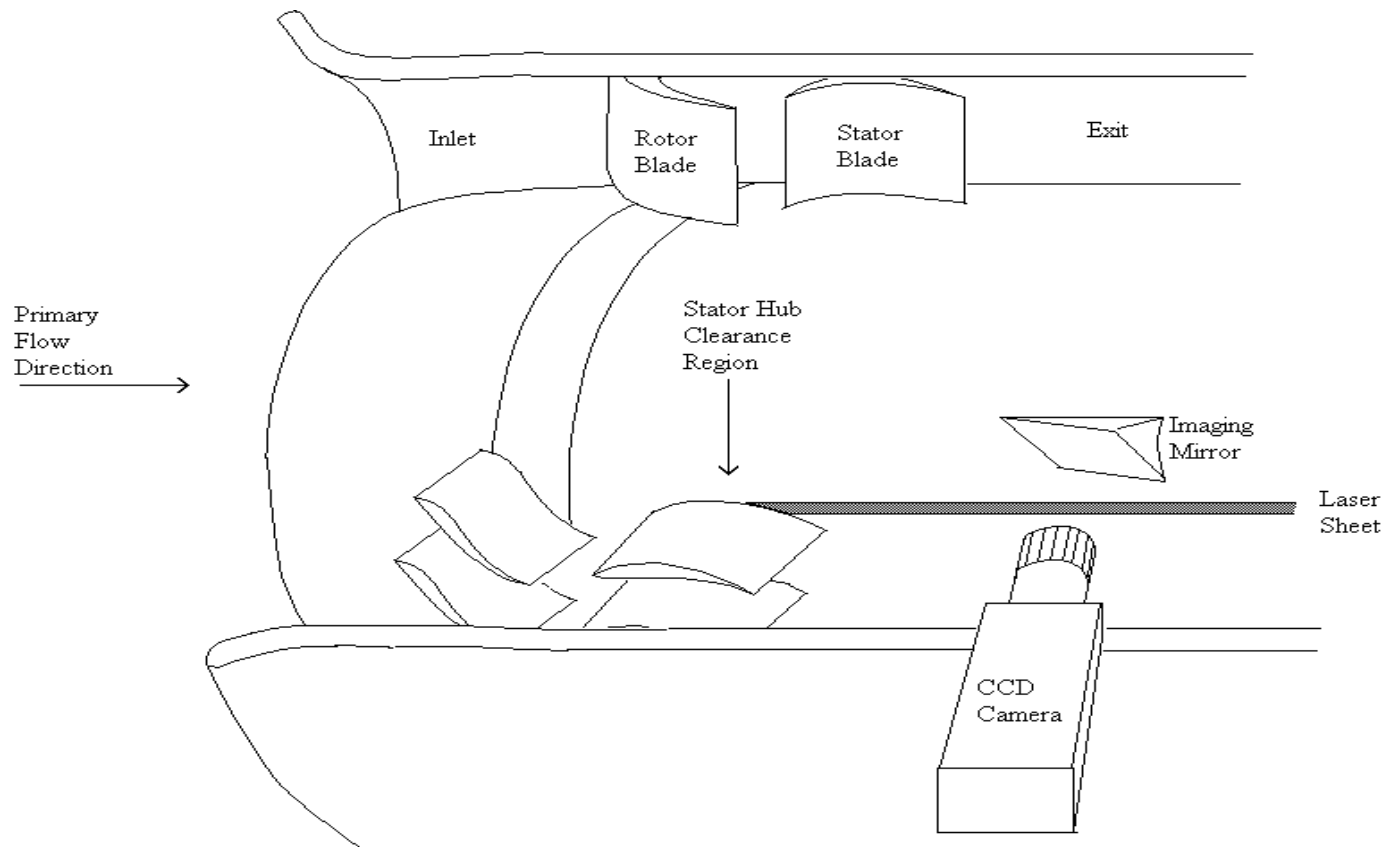
Compressor performance and vane aerodynamic loading are of interest

- **Compressor Performance is determined using conventional instrumentation**
 - **Stagnation pressure rakes and hub and casing static taps**
 - **Stagnation temperature rakes**
- **Stator vane aerodynamic loading quantified using surface static pressure taps**



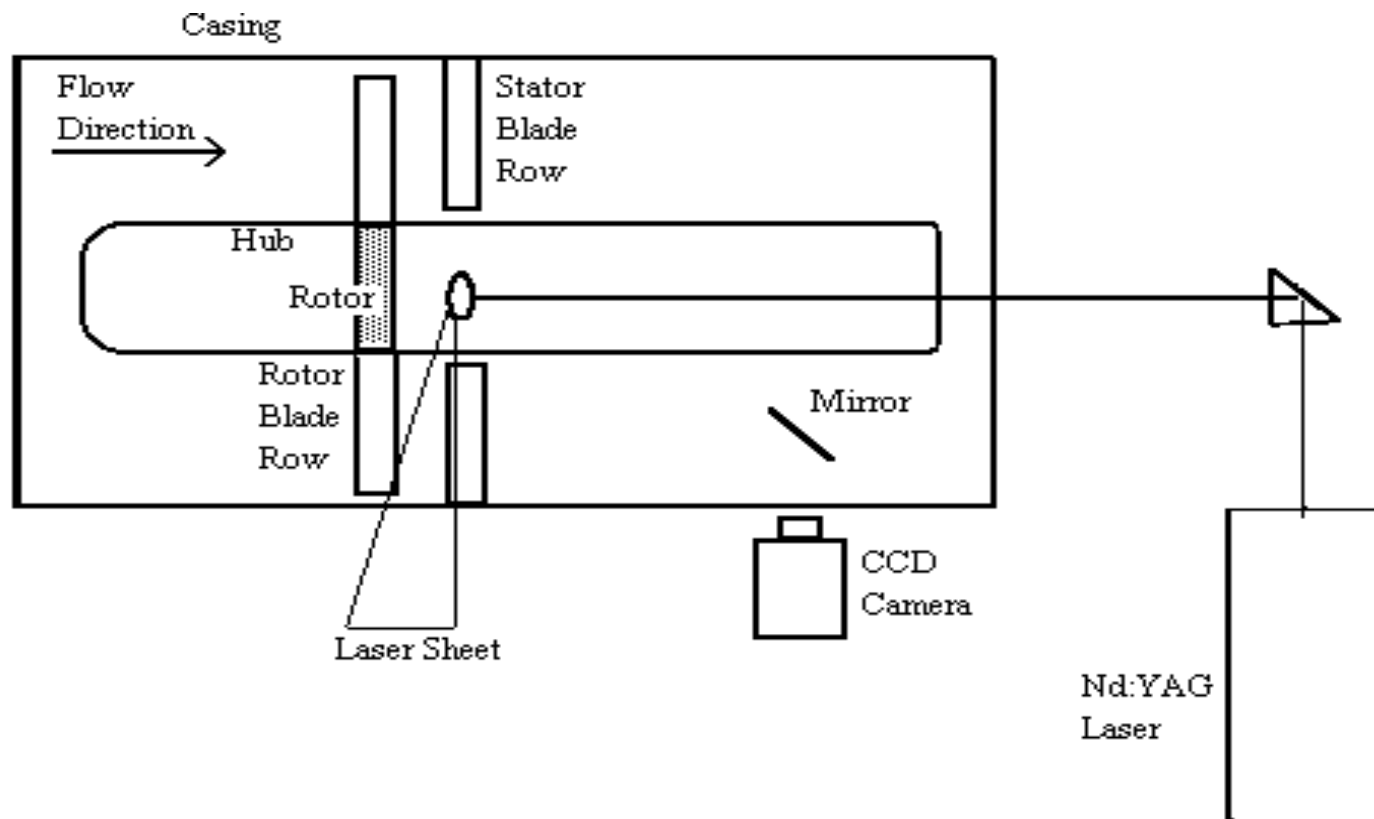
INSTRUMENTATION

Particle Image Velocimetry (PIV) will be used to measure the hub clearance flow field



INSTRUMENTATION

Particle Image Velocimetry (PIV) will be used to measure the hub clearance flow field



BENEFITS TO ATS PROGRAM

- **Provide benchmark experimental data to evaluate current CFD models and direct the development of future models for flow predictions in the endwall and clearance regions**
- **Accurate clearance models can be used to develop passive/active methods to reduce clearance losses and therefore increase compressor performance**

TEAM MEMBERS

Research program has university and industry participation

- **University of California, Davis**
- **Solar Turbines, Inc. , Industrial Advisor**

FISCAL YEAR 1998 ACTIVITIES

- **Design experiment**
- **Design new stator vanes**
- **Fabricate & instrument stator vanes**
- **Initiate rotating hub experiments**